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RECENT SUGGESTIONS IN DIESEL-ENGINE CONSTRUCTION

By F. Ernst Bielefeld

From "Schiffbau," June 2, June 16, and July 7, 1926

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By F. Ernst Bielefeld.

The multistage injection-air compressor of the Diesel engine is a special auxiliary mechanism which considerably increases the original cost of the engine, the cost of operation 7 to 12% by the consumption of energy, and the weight of the power plant from 10 to 33%. Moreover, it causes disturbances in operation which must be taken into account. Naturally it must continue to be used until some other way is found for the satisfactory combustion of the fuel in high-pressure engines. Considerable progress has been made recently in the construction of "airless" Diesel engines (i.e., with direct mechanical injection, without the use of compressed air). There are already several apparently reliable Diesel engines without multistage air compressors. These were made possible by the invention of high-pressure fuel-injection pumps, which function with soft-metal packing, without troublesome stuffing boxes. In the new pumps, the pistons and cylinders are hardened and polished. Moreover, reliable valves and fine injection nozzles have been invented. Other important improvements are the rigidity of all the pump compartments and injection passages, the complete elimination of air from the fuel and the prevention of the formation

*"Neueste Bestrebungen im Bau von Dieselmotoren." From "Schiffbau," June 2, June 16, and July 7, 1926.

of gases or vapors inside the pipes and passages. Compressorless oil engines with small and medium-sized cylinders can now be made without difficulty. Larger cylinders, such as come under consideration in low-speed engines for commercial navigation, have not yet been attempted. Large combustion chambers have not yet been satisfactorily supplied with fuel by means of a single nozzle, or a number of nozzles arranged in the center of the cylinder cover. The penetrating distance of the fuel jet is but slightly increased by increasing the pump pressure, while the fineness of the atomization is increased. Larger combustion chambers can therefore be satisfactorily supplied with fuel, without a great increase in the pump pressure, only by the suitable distribution of several nozzles in the cylinder cover. Such an arrangement is, however, opposed to the desirability of keeping the cylinder cover as free as possible from special stresses. The cylinder cover should be made as a body of rotation without perforations outside its center. Examples of such structures are the well-known arrangements by Sulzer and the Bethlehem Steel Company, as also the large Diesel engine made by the North British Diesel Engine Works from designs by J. C. M. Maclagan. Even the large battleship oil engines of the M.A.N. and of the Friedrich Krupp Germaniawerft (which were destroyed in accordance with the stipulations of the Treaty of Versailles) show progress in this direction.

Since, however, reliable fuel-injection pumps can now be made for pressures of over 500 atmospheres, nothing further stands in the way of making a large Diesel engine with an injection device in the axis of the cylinder and an ideal form of cylinder and cylinder cover. It is yet undecided as to whether such an engine can be more feasibly built as a double-action engine with piston rod and stuffing box in the lower part of the cylinder, or as an improved Junkers engine, or as a simplified Maclagan engine, or otherwise.

The use of compressed air for starting is reduced to a minimum by the well-known reversing gear of the Vulcan Werft and others. The compressed air required for starting can be produced by an auxiliary compressor.

The combustion is not really controlled, either in the Diesel engine with air injection, or in compressorless engines with ignition chamber or mechanical injection. Losses occur in all oil engines through turbulent air injection or airless injection. The fuel efficiency can be considerably improved by the introduction of perfectly controlled combustion.

The extensive adoption of Diesel engines of all kinds has considerably increased the demands for and the price of this fuel. The question is even raised as to whether coal will not regain its former ascendency as a ship fuel. This question can probably be answered negatively. At any rate, there are still many oil wells, and it has been found possible to liquefy coal

with the aid of hydrogen, at pressures above 100 atm. and temperatures above 400°C (752°F.), according to the method of Bergius and Billwiller (Cf. V.D.I. - "Zeitschrift des Vereines deutscher Ingenieure," 1925, pp. 1313-1320 and 1359-1362).

Naturally, it is still being endeavored to lower the cost of operation, i.e., the cost of fuel. The heat losses through the cooling water or air, which are also functions of the time, can be diminished by using higher revolution speeds. The fuel consumption of a Diesel engine with air compressor has already been attained in carburetor airplane engines. The trunk piston and the customary crank shaft drive seem, however, to interfere with the use of very high speeds. The lateral pressures of the piston can be diminished by a beam drive, though perhaps it would be better to use an entirely different driving gear, possibly even free pistons. With only one crank shaft and opposite-working pistons, the revolution speed can not be very high, because the upper piston with its crosshead beam is too heavy. Junkers could not, therefore, raise the revolution speed of his new airless-injection engine above 500 R.P.M. ("V.D.I. Nachrichten" 1925, No. 35, p.2, and "V.D.I." 1925, pp.1369-1378). Should it be desired to reach high revolution speeds with engines having opposite-working pistons, one crank shaft would have to be located on each side of the cylinder, which was proposed. In the Michel engine (Cf. Nagel, "Die Dieselmaschine der Gegenwart," "V.D.I." 1923, p.713), a high piston speed can

be attained by using one combustion chamber for three radially arranged cylinders. It is, however, reported that the roller bearings, which trnasmit the pressures to the revolving track, have not yet functioned with entire satisfaction, and also that the crossheads do not work perfectly.

The increase in the compression pressure and combustion pressure would also improve the heat efficiency of the Diesel engine. At the Vickers plant, a Diesel locomotive engine, built according to the ideas of Schelest, is being tested, to which the air is delivered at a preliminary compression of 10 atm. and by which the compression is increased to 60 atm. With the use of plungers and the customary crank shaft drive, the high lateral pressures of the piston would become unpleasant. In crosshead engines sufficiently large surfaces could be provided in the crosshead guides, but considerably better results could be obtained with the aid of a beam drive, since all the bearings could then take the form of roller bearings. The transmission between the crank shaft and piston can also be accomplished with the help of a beam drive (Fig. 1) and the expansion can thus be increased (Powell).

Another way would be to use the compound arrangement, in which, however, the high-pressure part would be made very short-hubbed and very speedy. Sperry has already attained a fuel consumption of 137 g (0.3 lb.) per HP./hr., while the lowest figure reached by the Deutz mechanical-injection engine was

165 g (0.36 lb.) and by the Junkers engine 157 g (0.35 lb.). By using a rapid high-pressure part and a somewhat slower low-pressure part, the 137 g figure can be improved. In the Bielefeld experimental compound Diesel engine, the high-pressure piston ran 18 times as fast as the low-pressure piston, whereby the losses through the cooling water and the exhaust were greatly reduced. This result could be attained only by the use of light-metal pistons, large piston pins and roller bearings for the connecting rod, the beam and the crank shaft ("Schiffbau" 1925, No. 9, pp.279 ff). Moreover, the compression in the high-pressure cylinder was considerably increased. The higher the compression is carried, just so much nearer to one another do the oxygen molecules lie, just so much more rapid is the reaction of the injected fuel with them and just so much swifter is the combustion. The swifter this is, however, the higher are the temperatures and pressures and the higher also is the thermal efficiency. The more rapid the expansion of the hot combustion gases in the high-pressure part, just so much shorter is the period of contact with the walls and just so much smaller will be the losses through the walls to the cooling water. The cooler, partially expanded combustion gases do not lose nearly so much heat as the gases in ordinary single-stage engines.

Furthermore, the combustion can be accelerated by the finest possible atomization of the fuel with controlled air delivery, for the smaller the fuel drops are the more rapidly the

oxygen can come in contact with the fuel molecules. Preliminary heating of the fuel would likewise accelerate the combustion process. Combustion efficiency is also increased by high compression, rapid combustion, rapid compression and expansion, compound action, recovery of heat from the exhaust and improvement in the driving gear with a diminution of loss through friction.

One way to reduce the fuel cost of the Diesel engine is the use of coal dust, possibly combined with fuel oil. R. Diesel tried to invent a coal-dust engine. A fellow worker of R. Diesel, R. Pawlikowski of Görlitz, developed a marketable coal-dust engine. On the occasion of the regular meeting of the "V.D.I." at Augsburg in May, 1925, Pawlikowski showed me an indicator diagram of this engine, which indicated perfect combustion. In the meanwhile, the D.R.P. (German patent) 417081, Kl. 46a, Gr. 29, of February 20, 1923, had been granted. The dry coal dust is carried in the intake direction by a worm pump and delivered in a previously exhausted chamber. After the delivery pipe has been shut off, the coal dust is injected by means of compressed air. The measuring process is identical with that of the D.R.P. 304141, Kl. 46c, Gr. 7, of May 2, 1911 (Bielefeld), in which the fuel is likewise conveyed into a previously exhausted measuring chamber.

A report was made some time ago on the solid-fuel engine invented by A. Schnürle (D.R.P. 398997, "Schwäbische Huttenwerke Actiengesellschaft," Stuttgart). This method, in which a liquid

could not be used in any case, proved to be impracticable. The grate built into the engine soon became clogged. Prospects are probably offered only by the coal-dust engines in which the coal dust, possibly mixed with oil, is mechanically injected.

According to D.R.P. 411409, Heitmann used easily inflammable fuel and difficultly volatilized, highly inflammable engine oils in finely atomized form.

There are yet no indications of a really rational exhaust-heat utilization in Diesel engines. The Scott-Still combination Diesel and steam engine and the Parsons Diesel engine ("Schiffbau" 1925, p.579) are only very modest experiments.

Far more would be accomplished by the high-temperature cooling of the combustion chamber under high pressure and the high-temperature cooling of the rest of the cylinder. The engine shown in Fig. 2 has a special combustion chamber whose walls are in the form of a Benson boiler (225 atm. at 374°C). The cooling medium is kept in circulation during the combustion process by a high-pressure pump.

Very different ways have been tried for building Diesel engines without air compressors. Diesel, Höflinger, Trinkler, Haselwander, Berglund and others have labored in the field of engines with auxiliary pistons, without having attained enduring success. Many attempts have been made to produce, with the aid of an explosion in an auxiliary chamber, a gas pressure which should take the place of the injection air. Another way

was mechanical injection, in which the pump pressure was transmitted to the combustion chamber. The pump was then further improved for high pressures. The fuel is now injected into ignition-chamber and displacer engines at pressures of 80-100 atm., while pressures of 150-500 atm. are used in mechanical injection. During the world war, Vickers used pump pressures of 350-450 atm. in submarine engines. After operating a short time, the pump pressure dropped to 150 atm. due to the yielding of the stuffing boxes. The stuffing boxes can now be eliminated and high reliable pressures maintained. At pump pressures below 80 atm., with the customary nozzle cross sections, the penetrative power of the fuel jets is too small in the hot combustion air, and the lacking energy must be supplied in some other way. Such a way is found in the displacer engines of Brandis-Deutz, Crossley, Hemag, Kaelble and Scharbau (R. Wolf Company). In still another way a whirling motion can be imparted to the air by a special form of the inlet valves or ports. In this connection the names of Klein (D.R.P. 318165, now contested by Junkers), Hesselmann, Hawa and Arco are best known.

In Germany, the engines of Deutz, V.M. type, M.A.N., Krupp, Junkers and Hille have been made for mechanical injection, with or without air circulation. The fuel is injected through openings about 0.2 mm (0.008 in.) in diameter. These form thread-like fuel jets, which break up into drops only at some distance from the outlet openings. Considerable fuel comes in contact

with the walls on which there is a deposit of oil carbon and lubricating oil, so that there is always an after-burning and the formation of a black smeary deposit. The harmful after-burning and deposits can be prevented only by fine atomization. For this purpose very fine outlets (valve slots, lip nozzles and slot nozzles) are necessary. The pump pressure must in some cases be very high and the mixing of the combustion air and fuel vapors must be controlled.

As regards the most complete heat utilization, the Diesel engine stands at the very beginning of its development. The attempts of Still and Parsons to utilize the heat of the exhaust gases in a steam engine, and the experiments with Sperry's compound engine, in which the thermal efficiency is supposed to be improved by far-going expansion, are only timid steps. Existing forms have been retained and progress has been very cautious. Perhaps bolder innovations would have been more successful. We are yet very far from achieving the heat-insulated cylinder, which R. Diesel attempted to obtain in his "rational" Diesel engine after the Hargreaves type. Perhaps an approximate solution of this problem is no longer distant. The whole cylinder does not need to be immediately insulated, as the insulation of only the combustion space would bring progress. The mushroom piston head used by Friedrich Krupp is a start in that direction as also the hot bulb of the hot-bulb engine. Since no metal can stand very high temperatures permanently, it is neces-

sary to conduct the surplus heat away, in order to avoid heat stresses. Copper, silver, and the light metals absorb much less heat than cast iron. We would not make much progress, however, by the use of these metals. Another way is being tried in the United States, first on explosion engines, namely, heat-insulated pistons. The material used is "bakelite C." Bakelite is an artificial resin made from formaldehyde and phenol (carbolic acid), which is converted, by heating under pressure in iron molds, into the infusible bakelite. The production of castings is similar to that of hard rubber articles, which are vulcanized in iron molds. Bakelite has hitherto been used for insulating walls in electrical apparatus. It is not perfectly fireproof, however, so that the surface exposed to the flames must be provided with a hard heat-insulating layer. Figs. 3 and 4 show the device invented by the writer for holding the insulating material (asbestos) with the aid of an openwork grating of bronze, which is secured by pressing into grooves in the bakelite piston. Since asbestos absorbs lubricating and fuel oils, it very soon becomes impregnated with oil carbon.

Fig. 5 shows a second design, in which a graphite disk (bottom of a smelting crucible) is used for the piston head. Of course any possibility of the piston's taking fire must be avoided. Since copper absorbs only half as much heat as cast iron or steel, only a small fraction of the heat is absorbed by the metal armature of the bakelite and transmitted to the cylinder walls.

It is also possible to insulate the piston head and the combustion chamber with "keramonit," which is an elastic compound made from chrom-iridium wire gauze and the ceramic compound "thermonit." The mass thus obtained is dried and burned. Thermonit is made by the Vinco Company of Berlin and is used for the so-called "flameless" combustion (Bone-Schnabel) and for insulating.

Pieces molded from a sufficiently pressure-resistant and fireproof substance can be set into the walls of pistons, cylinder covers and the combustion part of the cylinder, as shown in Figs. 6-7.

It would be desirable to have experiments undertaken in this direction. There are also other thoroughly practicable ways. No detailed report, however, can yet be made regarding them.

Much can be accomplished by rapid combustion, in which the finely atomized fuel is burned so quickly with a short flame, as to avoid contact with cold walls. By the customary method of injecting the fuel into the combustion chamber, it is always brought into contact with cold walls. The frictional resistance of the compressed hot air is in fact not important for large fuel drops with high penetrative power. On its way through the hot air, however, the fuel drop absorbs heat and its outer portion is vaporized and, since the vapor adheres to the surface, the size of the drop is increased and its frictional resistance

in the air is increased, as illustrated by Fig. 8. Very soon after its injection, the oil vapor ignites on the surface of the drop, which is still cold inside, and the burning oil vapor and the gaseous combustion products likewise adhere to the drop, due to gravitation, as shown diagrammatically by Fig. 9. The bringing of the oxygen into contact with the fuel molecules is rendered difficult by the combustion gases and the nitrogen in the air. Fig. 10 represents the probable distribution of the constituents of the combustion air and a fuel drop penetrating the air. The oxygen molecules must first find their way with difficulty, in order to be able to combine with the fuel molecules. It is only a short distance from the point of injection to the piston head or cylinder wall, so that only a portion of the drop is burned before reaching the cylinder head, where a new danger threatens it. Like greedy dragons there open before it the microscopically fine crevices in the construction material or the pores of the absorbent oil carbon. Fig. 11 is a microscopical picture of a thin smooth surface layer of a piston, while Fig. 12 represents the same layer covered with oil carbon, which has attracted the oil globules and coated itself with them. It is only after one has made such investigations, that he understands why combustion requires so long a time in a Diesel engine. In the case of injection by means of cold air, the combustion suffers a further disturbance, which does not occur in Diesel engines with airless injection. The fuel must, however, be coarse-

ly atomized, so that the drops will have momentum enough to penetrate the whole combustion space. If the atomization were very fine, the drops could not penetrate the hot air and would form vapor clouds about the nozzles, which the oxygen could not penetrate. Fig. 13 shows the fuel jets in the so-called mechanical injection with a hemispherically hollowed piston head. The fuel strikes the hot piston head and is deflected in all directions and reaches the walls and cover of the cylinder. The distribution of the temperatures in the combustion space might occur as shown in Fig. 14, the cross-hatched portion in the upper part of the combustion space being the hottest zone. Toward all sides (i.e., toward the colder walls) the temperature decreases. Of course the fuel passes smoothly through this hottest zone. Hence it would be better to have a different temperature distribution, which might be obtained by heat insulation (Figs. 2 and 7).

In the combustion space according to Fig. 13, the walls receive a large share of the fuel, which is only made accessible to the oxygen of the air by gradual vaporization. There are formed, therefore, in the vicinity of the walls, zones in which the after-burning occurs. Fig. 15 shows the approximate distribution of these zones. In "V.D.I." 1924, p.1355, Lindemann shows that, in the compressorless Deutz VM engine, the losses through poor combustion are as large as the losses resulting from the multistage compressors in an engine with air-injection

atomization. The deeply concaved piston head works like a hot bulb, so that the lubrication of the piston must be very carefully attended to. The greatest care must be taken that the upper piston rings be cooled by fresh cylinder oil and that the formation of the smeary black deposit be prevented as much as possible. Deutz has therefore added a special high-pressure oil pump for the lubrication of the piston, this pump being operated by a valve-tappet rod. Some of the lubricating oil naturally runs over into the concave piston head, is there vaporized, and is partially burned with the injected fuel.

Similar phenomena occur in ignition-chamber engines, with the further disadvantage that the ignition chamber remains filled with exhaust gases and very often contains unburned fuel, so that the fuel consumption of ignition-chamber engines is somewhat greater than that of mechanical-injection engines.

Fig. 16 shows the after-combustion zones in an ignition-chamber engine, as well as the ignition chamber filled with exhaust gases. In ignition-chamber engines it is therefore desirable to make the neck between the ignition and combustion chambers as wide as possible and its contents as small as possible. In the new two-stroke-cycle engine made by Friedrich Krupp of Essen, the neck is so wide that it no longer constitutes a separate chamber, but only an extension of the combustion chamber.

In order to avoid the losses through after-burning in mechanical-injection engines, it must therefore be endeavored to

prevent the fuel from reaching the walls by atomizing it as finely as possible. Moreover, an increase in the compression is advantageous, since the greater the compression, the nearer the oxygen molecules are to one another and the more rapid the combustion will consequently be.

Here new difficulties arise, since the production of very fine nozzle openings in correspondingly hard and strong materials is impossible. According to D.R.P. No. 352078, the M.A.N. has attempted a solution by casting fine cores in some material like porcelain, etc. Fig. 17 shows the imbedded cores, 3 in the cope 1 and the drag 2. The casting is a cylindrical body formed by the rotation of section 4. Figs. 18-19 show the cores 3 in cross section. The writer tried another way, by making fine grooves in the annular surface of the shoulder formed by the head of a cap screw and screwing it tightly against an insert. The grooves then formed very fine channels (see "Motorwagen" 1915, p.470, Fig. 14). According to D.R.P. No. 369670, of January 11, 1921, Junkers uses a needle, on whose cone fine grooves are made, and presses this into a corresponding conical sleeve, so as to produce two fine channels, which terminate in small holes in the oil-delivery pipe. The drilling of these holes in hard material is expensive. The writer therefore suggests the use of disks, truncated cones and similar bodies, in which the holes for the admission of the fuel can be cast, thus forming a cage for holding these bodies.

Such a nozzle is shown in Figs. 20-21. This cage is also water-cooled or oil-cooled, so that the device can be pushed far into the combustion chamber. It contains the disks or bodies, which are polished so as to be perfectly flat and parallel, and one of which contains the grooves or depressions shown in the plan view (Fig. 21). These parts, when joined, form fine channels. Fig. 22 shows another form. Here four bodies are combined, so as to form a sprinkler.

Such very fine nozzles require corresponding fuel pumps. Accumulator pumps are probably the best, in which the pump piston is likewise the accumulator piston. Fig. 23 shows such a pump. The cam raises the pump piston, by means of a roller, against the pressure of a strong spring. The piston thus makes its suction stroke under mechanical control. As soon as the roller leaves the cam, the liquid in the pump is subjected to the pressure of the spring. The injection then takes place, until the overflow-valve is opened by a push rod operated by the piston. With this pump no subsequent injection can occur under too low pressure. Moreover, the amount of the pump pressure can be very easily regulated. At very high pressures (500 or more atmospheres) the piston can be packed in two stages, as represented in Fig. 24.

The very fine nozzles (Figs. 20-22) can now be located over the center of the combustion chamber. Hereby, as indicated, the air circulation according to Klein or Hesselman can be used, in

order to accelerate the combustion. With large cylinders two nozzles can be used (Fig. 27), with only two outlets each, so that most of the air comes in contact with the fuel. Still better is the arrangement according to Fig. 28, whereby the fuel jets are pointed in the same direction as that of the circulating air. The combustion flames are here very short, after the nature of a welding flame. Furthermore, knife-shaped, water-cooled catalyzers can be so arranged that a portion of the fuel will come in contact with them and be catalytically decomposed. Thus a saving of ignition fuel can be effected in tar-oil Diesel engines.

Of course other types of nozzles can be located on the circumference of the cylinder (Figs. 29-30). With small cylinders, larger nozzle openings can be used. Such nozzles consist essentially of truncated cones (Figs. 31-32), which are polished on the adjoining surfaces and whereby on one of these surfaces grooves are made which form channels when the surfaces are pressed together. The fuel delivery pipe must be so constructed that the nozzle will be automatically deaerated, which, as the diagram shows, offers no difficulty.

Very small injection valves can be used just as well, provided the combustion chamber is correspondingly constructed. Fig. 33 represents such a valve. It is stuck through a guiding. piece which is shorter than the valve. The valve stem projecting from this guiding piece is enclosed in a divided holder, on

which the valve spring acts. The holder is secured against turning, so that compression of the valve spring will not twist off the shank. Such valves can be produced down to a stem diameter of 1 mm (0.04 in.) and are just as reliable as the nozzle of a carburetor or a needle valve. Fig. 34 shows two concentric mushroom valves, whereby the emergent fuel sheets cross in the combustion space. The atomization with disk valves is just as fine as with Benkert nozzles.

For injection through valves opening into the combustion space, the latter must be either flat or, better still, pear-shaped, like Figs. 2 and 35, with a head piece on the piston for producing a circulation of the air. With this modified displacer engine, according to the new working methods of Bielefeld, a pressure difference of only 0.3-1 atm. is created by the head piece of the piston. The displacer head of Figs. 2 and 35 and the combustion chamber, with well-made and polished walls on all sides, is so shaped as to produce a quiet air circulation. The fuel injector consists of a very small valve, as shown in Fig. 33, which is subjected to a very high pump pressure and opens into the combustion chamber. The fuel is atomized so exceedingly fine under the high pump pressure that it has very little penetrative power. Hence the injection valve is advanced far into the combustion chamber and the air is guided, by the special shape of the combustion chamber, past the point where the fuel is injected. The exceedingly fine atomized fuel burns

suddenly in the same measure as it is injected and as the air comes in contact with it. Controlled rapid combustion is therefore practically attained and the fuel burns with a short flame like that of a welding burner.

According to the structure of the combustion chamber and the injector, the combustion can take place without pressure increase, i.e., at constant pressure or (which is much better), with considerable pressure increase. The fuel consumption of engines with mechanical injection are mostly lowered by these and similar measures. Very advantageous is the injection through the very small valve, whose construction is a difficult piece of precision work, but which, however, is perfectly reliable. The atomization is considerably finer and more uniform than that from injection through nozzles. There are no deposits of oil carbon, since the rapidity of the combustion excludes all contact of the fuel with cold walls, as well as any accumulation of fuel, through lack of oxygen. The formation of oil-carbon deposits is due to three different causes:

1. If the fuel oil comes in contact with cold walls, it is precipitated and then burned, with the deposition of carbon, through the radiated heat from the burning gases or through conducted heat;

2. The injected fuel vapor is so dense at one place that the oxygen of the combustion air does not suffice for combustion. Due to the prevailing temperatures, a gasifying process then

sets in, with the deposit of carbon;

3. Small drops from the after-dripping, and almost always from the fuel vapor, accumulate on the nozzle. These evaporate slowly with a deposit of oil carbon. The nozzle thus becomes fouled and the injection thereby impaired, even though the oil carbon is blown off from time to time by the high pump pressure. With the injection valve opening directly into the combustion chamber, no carbon can be deposited on the valve, and the injection is never impaired, therefore, by carbon deposits.

Fig. 36 shows the form of the combustion chamber of an engine with rapid combustion. Water-cooled knife-shaped catalyzers can be brought into contact with the flame in the combustion chamber, as shown to the right of the diagram. Figs. 37-38 show the air circulation and the injection. At a quarter-load, as shown in Fig. 37, the horizontally hatched portion of the air loop is utilized and at half-load the likewise horizontally hatched portion in Fig. 38.

While no very fine atomization of the fuel can be allowed in the engines with air circulation (according to Klein-Junkers, Hawa, Hesselman and the Friedrich Krupp Company) on account of the necessary distribution of the fuel through about half of the combustion space, the injection distance in the new combustion process is reduced at least an eighth of that in engines with disk-shaped or hemispherical combustion chambers. It must be endeavored to obtaim the finest possible atomization, so that

the combustion of every fuel drop will be accomplished in the shortest possible time. Since the highest temperatures are not in immediate proximity to the walls, but in the center of the combustion space, the heat lost through the cooling water is smaller than in the well-known engines, notwithstanding the enlarged surface area of the walls of the combustion chamber. There is here shown again, what Ricardo demonstrated for explosion engines, that the heat efficiency is not affected so much by the surface area of the combustion chamber as by its shape. Of course the injection must take place at the right instant, but this is no disadvantage, however, as has been erroneously claimed. The injection instant must be just as accurate in all other engines since, with too early injection, too high combustion pressures are produced and, with too late injection, afterburning occurs. With rapid combustion the tolerance for the injection timing is greater than in the usual turbulent combustion. Since the combustion is completed quicker, a late injection, which would produce a long after-combustion in any other engine, does not do so here, but the combustion ends almost instantly with the close of the injection. In very rapid engines, therefore, no preliminary injection is necessary and consequently the injection timing does not need to be retarded for starting. The attendance of the engine is thus considerably simplified. The new working method can also be used in two-stroke-cycle engines. The scavenging is then expediently so arranged

that the exhaust ports are at the bottom and the scavenge and supercharging ports are above them. Efficient scavenging can be effected by a corresponding arrangement of the scavenge and supercharging ports. Fig. 39 shows the exhaust and scavenge process. Fig. 40 shows the supercharging and the formation of an air loop. Fig. 41 represents the combustion space with air loop during the injection. Rapid combustion, with a short flame, also occurs as in the arrangement shown in Fig. 35, resulting in an exceedingly small fuel consumption.

The new working method can, of course, also be used in large Diesel engines. Figs. 42-43 show a displacer engine. While a disk valve can be located in the upper cover, very fine nozzles must be used in the lower cover with the stuffing box. The structure of such a fine nozzle is shown in Figs. 44-45.

Engines with pistons working in opposite directions (Junkers) are practically so constructed that the cylinder has no valve-cage housings in the combustion chamber. Fig. 46 shows such a cylinder, in which an annular piston is used above. The stationary central insert contains the injection and starting valves. The combustion is therefore a mechanically controlled rapid combustion according to the Bielefeld method. The cylinder can be of the same diameter throughout, or its diameter can be reduced at the top to correspond to the size of the central inset.

In the use of special auxiliary scavenge and supercharging valves, the type shown in Fig. 2 can also be used. Similar im-

provements are also possible in the Diesel engine with injection-air compressors. Here the fuel is injected separately from the injection air, and the latter serves chiefly to produce a whirling motion of the combustion air, so that it is compulsorily brought into contact with the fuel. Thereby the fuel can receive a high preliminary heating.

Moreover, an auxiliary piston, as shown in Fig. 47, can be used for producing a whirling motion of the air. Here the combustion air is first forced into the auxiliary chamber in the cylinder cover and then forced back again by the auxiliary piston. The communication between the remaining compression space in the working cylinder and the auxiliary chamber is formed by a neck, into which the injection valve projects. The compressed air is thus forced through the fuel spray. It is obvious that either oil vapors or gas can thus be burned under mechanical control. Attempts are being made in England to burn gas according to the Diesel method.

Lastly, the fuel can be burned catalytically or "flamelessly" according to Bone-Schnabel in porous stones with the aid of a movable auxiliary cylinder, as shown in Fig. 48. The porous stones (thermonite) are placed in the neck of this cylinder. During the compression, as in the previously described engine, the whole combustion air, even to that remaining in the clearance spaces, is transferred to the auxiliary cylinder. At the dead center, the auxiliary cylinder is moved outward, and the compressed air is forced back. The fuel is simultaneously in-

jected and is flamelessly burned, together with the air in the porous stones. The heat efficiency of the engine is considerably improved, since the combustion space is practically reduced to only a twentieth of that in normal Diesel engines.

Figs. 49-50 show the combustion chamber of Sperry's compound engine. In order to make the connections between the high-pressure and low-pressure chambers as short as possible, Sperry made the ground plan of the combustion chamber oval, so that the overflow valve goes through the combustion chamber. It must therefore be protected by piston rings, like a piston, against the high compression and combustion pressures. The valve must, moreover, be well cooled. Nevertheless, the heat losses are considerably smaller than in R. Diesel's first compound engine (Güldner, "Verbrennungskraftmaschinen," third edition, pp.704-705). In the writer's compound engine, mentioned in the introduction, this valve is eliminated. Moreover, the new engine works in a two-stroke cycle and employs the previously described rapid-combustion process.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

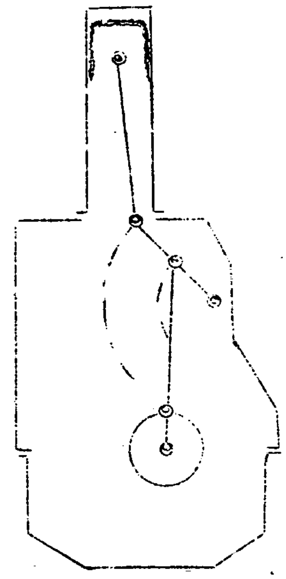


Fig.1 Crankshaft drive with beam.

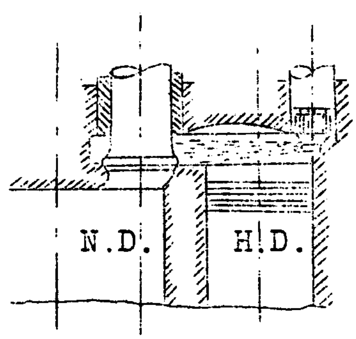
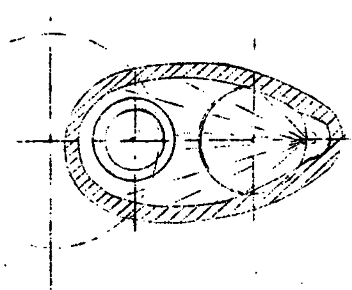


Fig.49.



Figs.49,50 Sperry's compound engine.
N.D. = low pressure.
H.D. = high pressure.

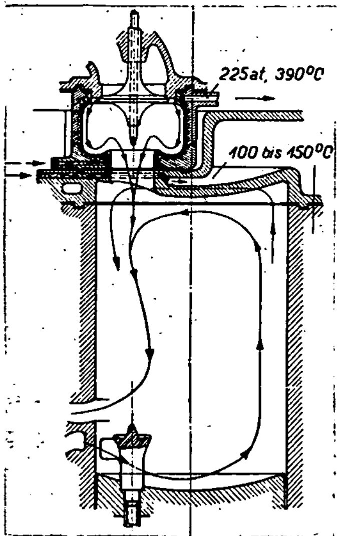
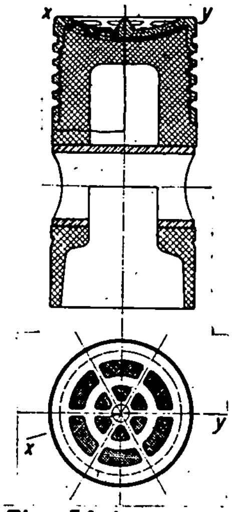


Fig.2 Two-stroke Diesel engine with special combustion chamber and high-temperature cooling.



Figs.3& 4 Bakelite C piston with asbestos head held by a metal grating.

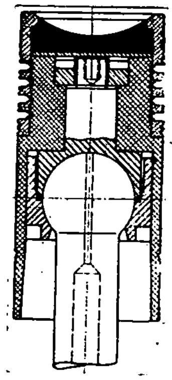
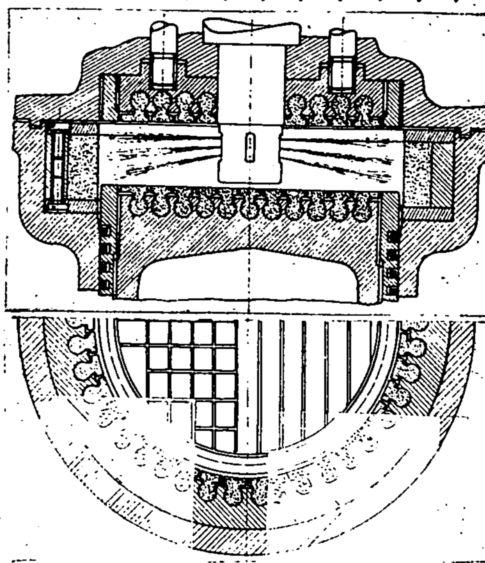


Fig. 5 Bakelite C piston with graphite head.



Figs. 6 & 7 Combustion chamber insulated by pieces molded from fireproof material.

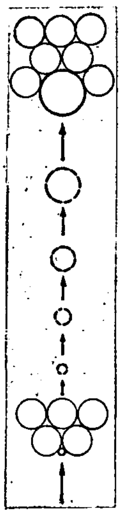


Fig. 8 Vaporization of an oil drop while penetrating the hot combustion air.

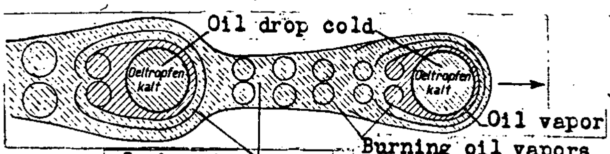


Fig. 9 Combustion of moving oil drops.

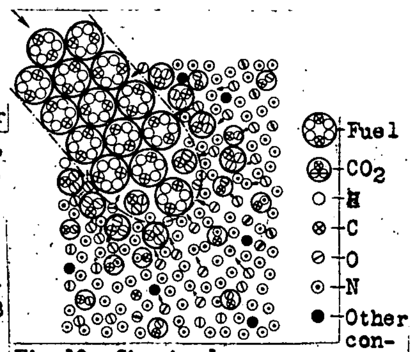


Fig.10 Chemical processes in the combustion of an oil drop.

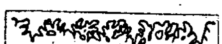


Fig.11 Thin layer from surface of smooth piston head

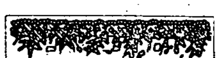


Fig.12 Thin layer from surface of piston head, with a coating of oil carbon, ashes and oil.

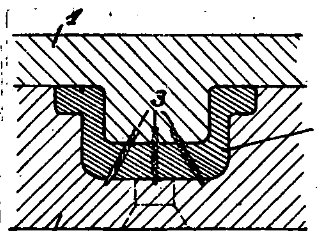
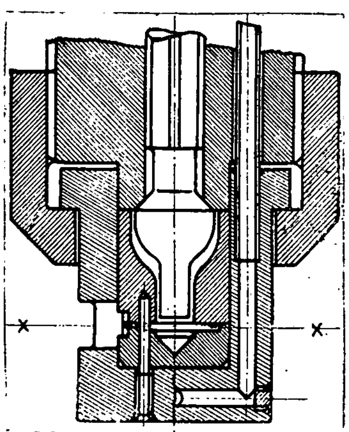


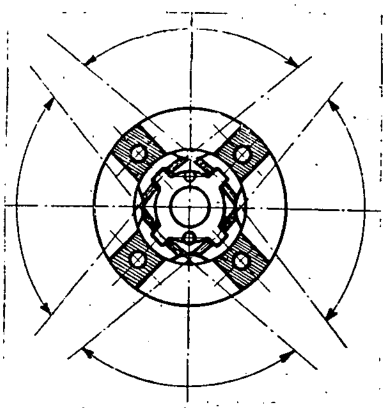
Fig.17

Fig.18

Fig.19

Figs. 17,18,19 Casting the nozzle for an M. A. N. engine.





Figs. 20 & 21 Nozzle with very fine outlet grooves.

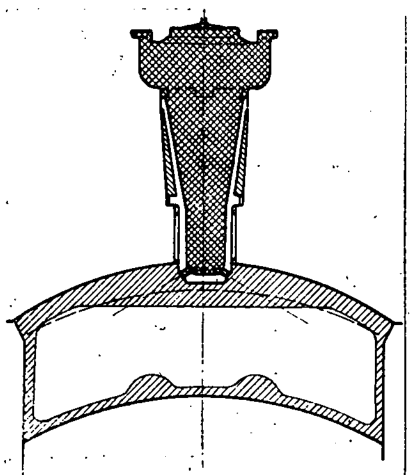


Fig. 16 Ignition chamber filled with gas residues and zones of after-burning.

6985·A.S

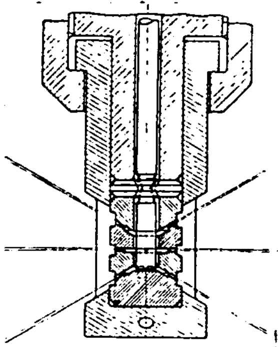


Fig. 22 Very fine nozzle (sprinkler type)

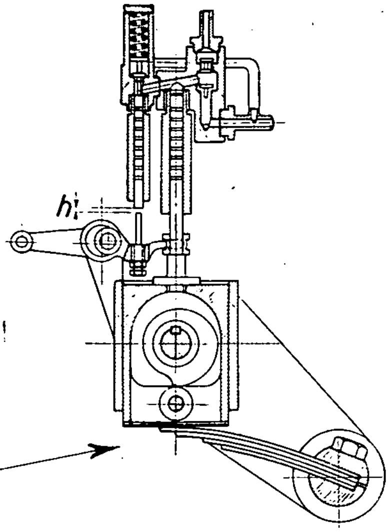


Fig. 23 Spring - operated pump.

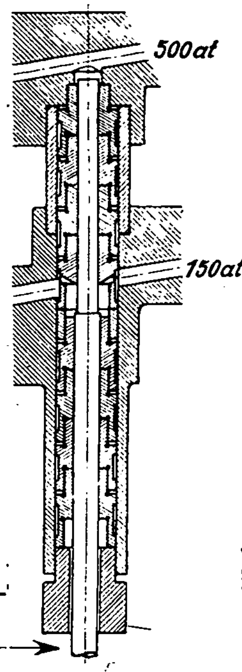


Fig. 24 Pump with lapped sub-divided barrel and two-stage packing.

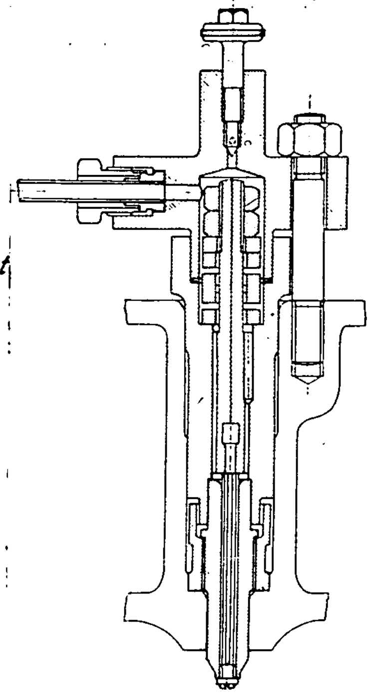
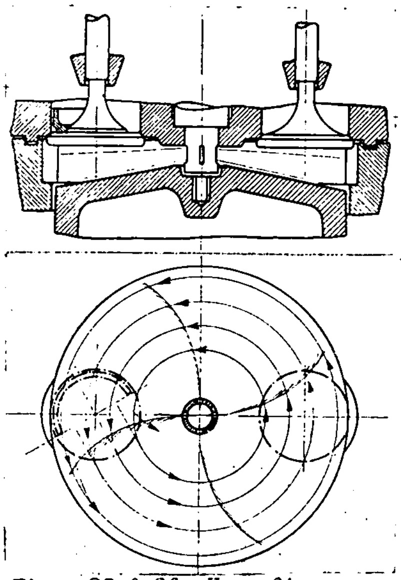
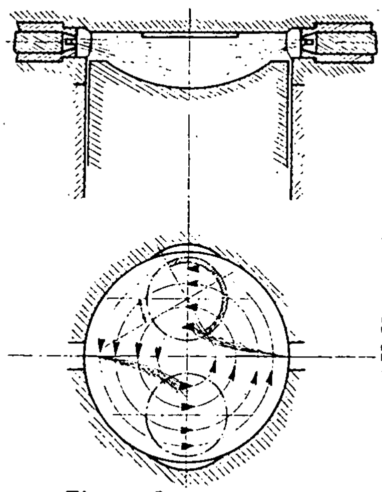


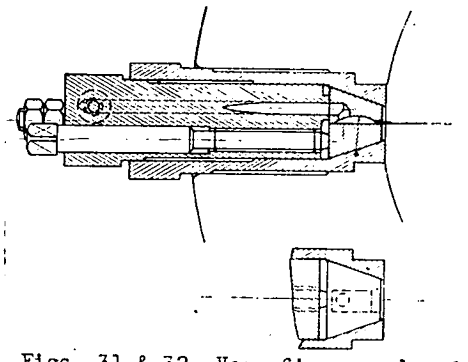
Fig. 33 Very small injection valve with cage.



Figs. 25 & 26 Very fine nozzles and air circulation.



Figs. 29 & 30 Two very fine self-deaerating nozzles for lateral arrangement in in cylinder cover.



Figs. 31 & 32 Very fine nozzles for lateral arrangement.

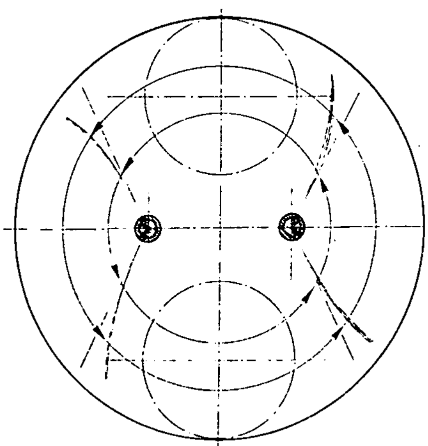


Fig. 27 Arrangement of two very fine nozzles in cylinder cover.

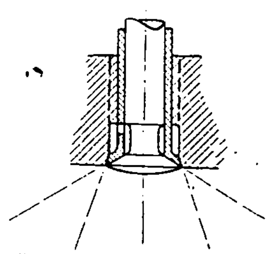


Fig. 34 Double valve for intersecting fuel sprays.

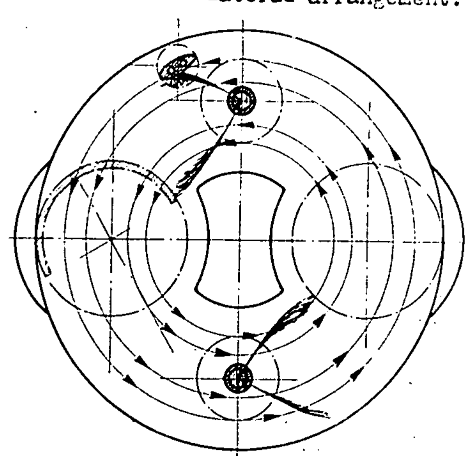


Fig. 28 Arrangement of two very fine nozzles in cylinder cover; air circulation and catalyzer.

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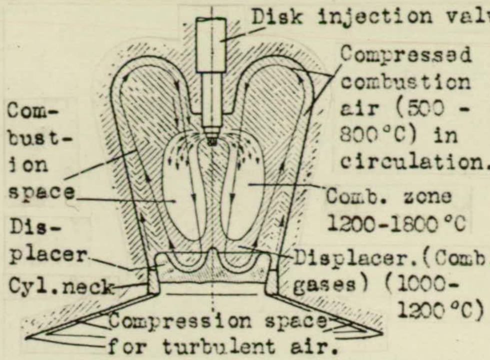


Fig. 35 Rapid combustion (Very fine atomization by very small valve.Air circulation by displacer piston head.)

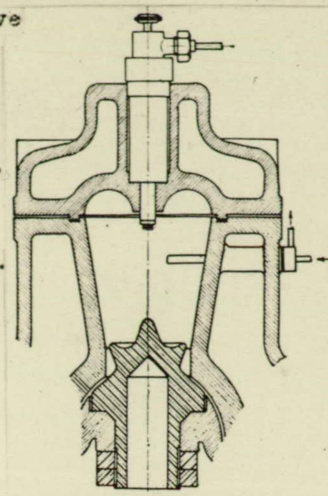


Fig. 36 Rapid combustion with catlyzer.

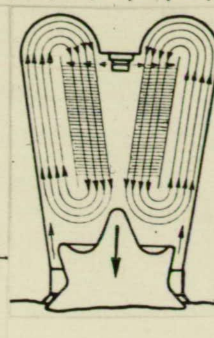


Fig. 37 Injection in rapid comb. (Quarter-load)

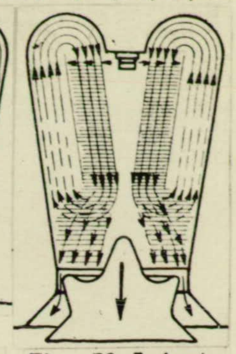


Fig. 38 Injection in rapid comb. (Half-load)

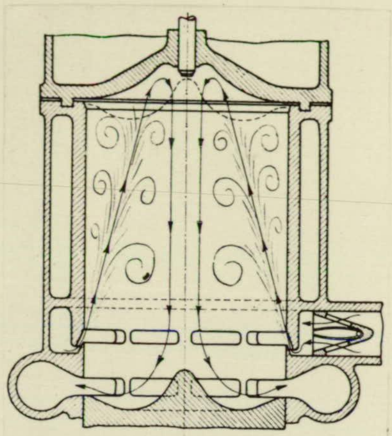


Fig. 39 Loop scavenging. Exhaust & scavenging.

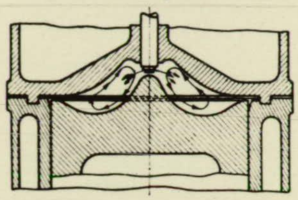


Fig. 41 Injection into air loops (Rapid combustion).

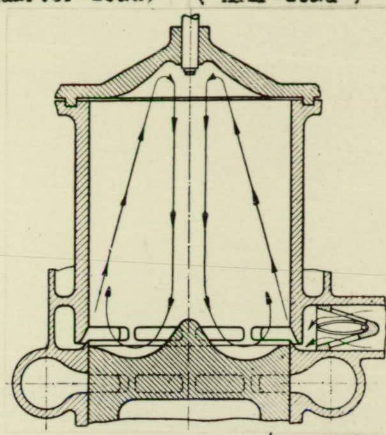
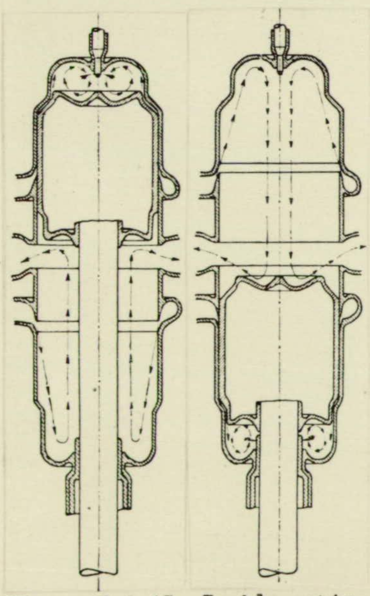
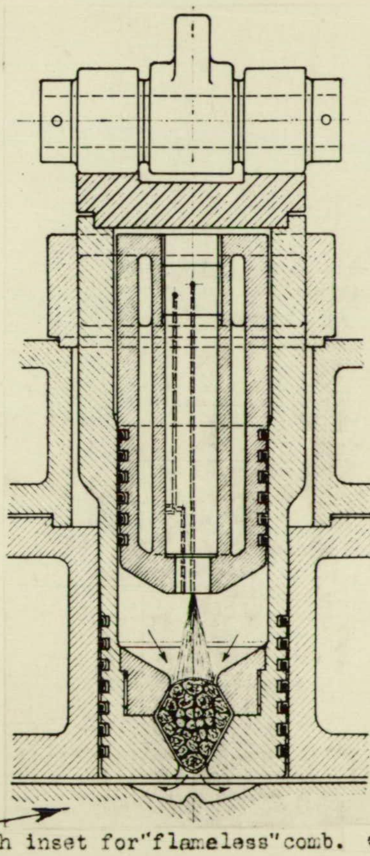
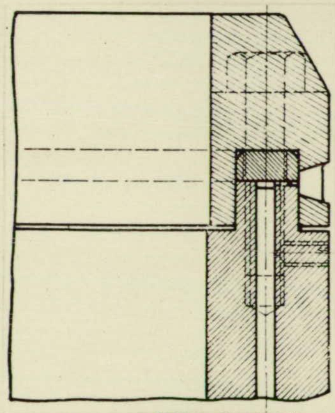


Fig. 40 Supercharging and formation of air loops.


Figs. 42 & 43 Double-acting Diesel engine with rapid combustion.





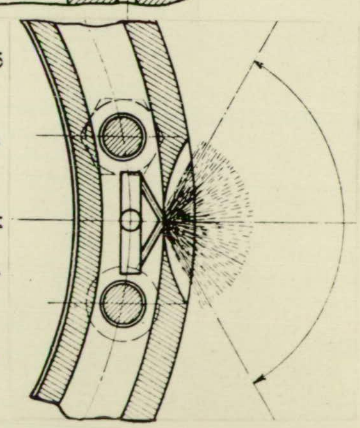

Figs. 44 & 45 Very fine nozzles on the stuffing box of the double-acting Diesel engine.

Fig. 48 Auxiliary piston with inset for"flameless"comb. 6984-A.S.

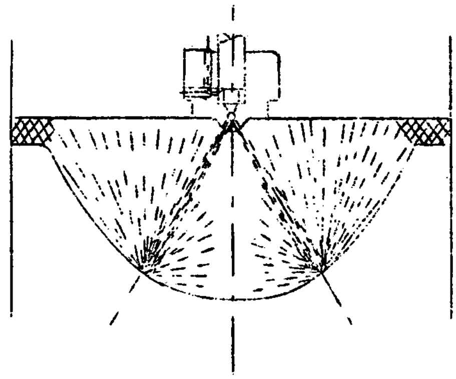


Fig.13 Mechanical injection with concave piston head.

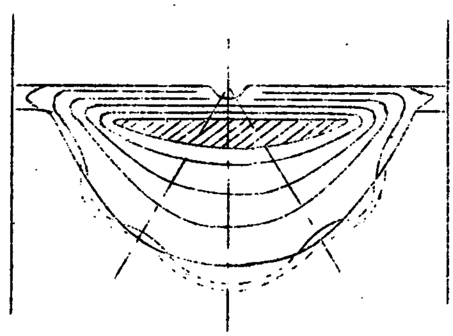


Fig.14 Temperature distribution in combustion space with concave piston head.

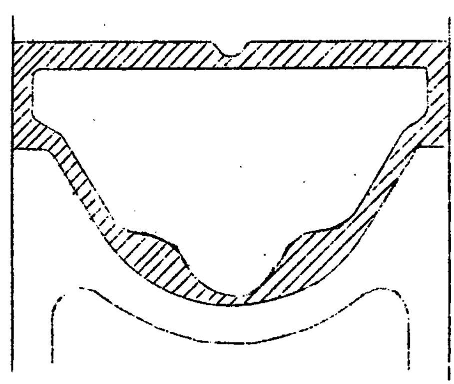


Fig.15 Zones of after-burning in mechanical injection.

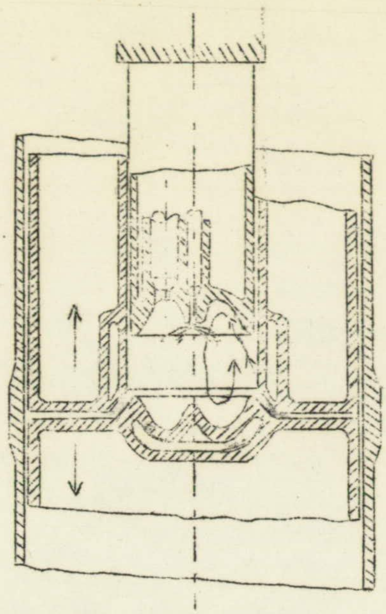


Fig.46 Engine with opposed pistons and rapid combustion.

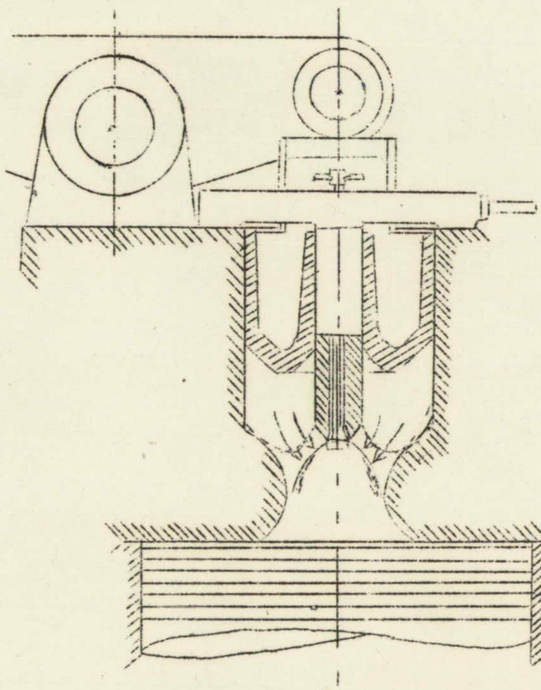


Fig.47 Auxiliary piston for forcing combustion air through the injected fuel sprays.